Solid lubricants

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PRODUCT REVIEW

The search for a cheap, clean and effective solid lubricant to replace messy oils and greases has been like the pursuit of the Holy Grail. Practically every conceivable material and combination of materials has been tried, 22,000 in one programme alone in the late 1950s, and there have been many false dawns as claims have proved ill-founded. The search goes on but, with the exception of polytetrafluoroethylene there have been few significant new discoveries over the last 50 years.

A solid lubricant is often defined as any solid material which reduces the friction and/or the wear of contacting surfaces in relative motion. A vast range of materials and coatings could be judged to behave as solid lubricants on the basis of this definition. For the purpose of this review, only materials which can be applied to a surface as lubricants, or incorporated in a coating on the surface or in a matrix to improve a material's frictional properties, will be considered.

Types

Solid lubricant types are, in the main:

lattice layer solids such as graphite;

other inorganic materials such as soft metals, oxides and ceramics;

organic polymers, soaps and waxes;

chemical conversion films.

Solid lubricants can be used in a number of ways. They can be applied:

as dry lubricants on their own;

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in a carrier fluid;

by being bonded to surfaces as coatings;

by forming part of metal- or polymer-matrix self-lubricating composites;

by incorporation in the recesses of porous or indented surfaces;

as additives in liquid lubricants;

by chemical conversion of the surface to be lubricated.

Lattice layer materials

Solids with a plate-like structure, also known as lamellar or lattice layer solids, include:

• boron nitride	BN
• graphite	C
• graphite fluoride	CF_x
• mica	$KAl_2(Si_3AlO_{10})(OH)_2$
• molybdenum disulphide	MoS_2
• talc	$Mg_3Si_4O_{10}(OH)_2$

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Also in this category are vermiculite and surface films of titanium di-iodide (TiI^sub 2^), chromium chloride (CrCl^sub 3^) and th disulphides of uranium and tungsten (US^sub 2^ and WS^sub 2^).

Boron nitride, like carbon, exists in two crystalline forms. Synthetic cubic boron nitride (CBN), which is one of the hardest materials known next to diamond with a hardness of 4,000HV and is used in cutting tools for machining hardened steel and nickel alloys. A lamellar form which resembles graphite (Figure 1) is sometimes called "white graphite". Its structure differs from those of carbon and MoS^sub 2^ in that each layer or cleavage face contains two different elements, boron and nitrogen. The - N bond must be partly ionic, resulting in the cleavage faces having both positive and negative charges. This increases its surface energy and hence the interface friction. The frictional behaviour of BN is similar to that of graphite, but the values are higher with coefficients of friction of 0.3 and above being measured. However the absence of oxygen has little effect on the friction of BN whereas organic vapours can more than halve the coefficient of friction. Above 500 deg C the friction of BN decreases, possibly as a result of the start of oxidation, while that of graphite increases. When heated in air boron trioxide is formed which softens and melts above 900 deg C.

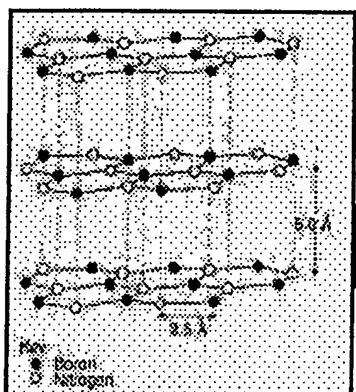

Figure 1: Structure of lamellar BN. The structure resembles that of graphite but the cleavage plane contains equal numbers of B and N atoms

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Figure 1.

Applications: mould facing material and release agent for glass moulds; dry lubricant in the temperature range 600800 deg C.

The addition of 20 per cent BN to hot pressed silicon nitride ceramic reduced friction and wear in self-mated tests, particularly room temperature but not in air with high humidity.

Graphite is one of the two naturally occurring crystalline forms of carbon. The other is diamond (Figure 2) in which each carbon atom is attached to four others by strong covalent bonds in a tetrahedral structure with the form of two interpenetrating face-centred cubic lattices. This gives diamond great resistance to plastic flow, a hardness of over 7,000HV (70GPa), an elastic modulus of over 1,000GPa and a specific gravity of 3.51. Graphite is at the other extreme of material properties. It is soft and black while diamond is extremely hard and colourless. As shown in Figure 3, with graphite the carbon atoms form a series of parallel layers known as basal planes made up of regular, chicken-wire like, hexagonal arrays of carbon atoms with covalent bonds. As each carbon atom is bonded to only three others, not the four that would satisfy all the valence bonds, electrons can move freely through the graphite crystal, making it a good conductor both of heat and electricity. The planes are relatively far apart and only weakly bonded although the effect of yr electron interaction can increase the interlayer bonding, particularly whe there are no gaseous contaminants in the operating environment to react with these irc electrons. The surface energy of the planes is low and deformation is easy by cleavage between the planes.

Graphite occurs in nature as a mineral with deposits in Sri Lanka, Malagasy, Siberia, New York State and Bavaria. In the sixteenth century graphite was discovered in the English Lake District and became the centre of the "lead" pencil industry whic lasted until modern times.

Most synthetic graphite is made from petroleum coke, a refinery byproduct. Graphitization of amorphous carbon is carried out temperatures between 2,600 and 3,000 deg C - the higher the temperature the greater the crystallinity and the better the physical properties of the graphite. Natural graphite has high crystallinity and low purity (80 to 90 per cent), while synthetic graphite has lower crystallinity but high purity (98.5 per cent). As well as a solid lubricant, graphite is used for electrodes, nuclear reactor moderator blocks, commutator brushes, rocket nozzles, the "lead" in pencils and for decorative purposes.

Other names

Apart from "lead", other old names for graphite are "plumbago" and "black lead". There are numerous references to the use of these materials as lubricants on their own and as additives during the Industrial Revolution of the eighteenth and nineteenth centuries. In 1779 they were shown to be a form of carbon but the familiar names are still in use.

Not an intrinsically low friction material

Graphite does not possess intrinsic low friction but relies on the presence of the normally present adsorbed layers of oxygen and condensable vapours such as water vapour or hydrocarbons on the edges of the platelets or graphite crystallites reducing the attractive forces between the laminates. Without these adsorbed layers, outgassed graphite suffers rapid wear and the friction coefficient is two or three times higher at around 0.4. Additives such as lead iodide, barium fluoride and, later, molybdenum disulphide were found greatly to reduce carbon brush wear in electrical equipment when operating at high altitud At temperatures above 100 deg C the adsorbates on the graphite lamellae responsible for low friction can desorb, resulting in rise in friction and wear. The use of suitable impregnants can raise this desorption temperature. In a vacuum or an inert atmosphere graphite not only is a non-lubricant but also becomes abrasive. A graphitized carbon brush which would last for 50 to 1,000 hours in air under the same load and at the same speed would wear at the rate of 1 to 2mm of brush length per minut At the same time it produces deep scratches in the surface of a copper slip ring. The effect of a small amount of water on the wear of graphitized carbon is illustrated in Figure 4.

An interesting effect has been reported when graphite slides against alumina ceramic in a vacuum. Over the temperature rang 600 to 1,500 deg C the friction coefficient was found to be low. This was attributed to a reaction between the graphite and oxygen atoms liberated by the aluminium oxide. The lower temperature limit for this tribochemical reaction could be reduced b introducing an easily reducible oxide into the ceramic.

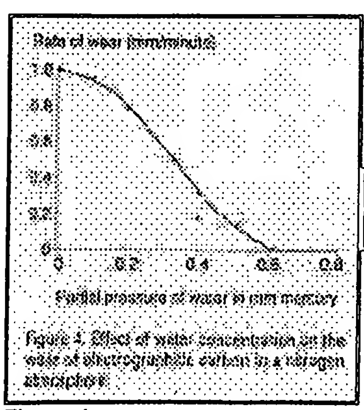

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Figure 4.

Graphite solid lubricant can be:

used in powder form;

made into blocks or sticks;

used as a dispersion in water, oil or volatile solvent;

used as a bonded film;

incorporated in polymers or porous metallic structures;

used to improve the frictional properties and machinability of mechanical carbons. Carbon made completely graphitic is too sof on its own for many mechanical applications.

Graphite dispersions

Colloidal dispersions of fine graphite particles ranging from 40 micrometres to submicron in size have an electronegative charg which assists in stabilizing the particles in suspension and in attaching the particles to metal surfaces of opposite polarity.

Other forms of carbon as solid lubricants

Some other man-made forms of carbon recently developed have attractive solid lubricating properties. Films of C60 Fullerene, an allotropic form of carbon, and diamond-like carbon (DLC) films, can give low friction values. Unlike graphite, their friction is lower in vacuum than in air. It has been found that when sliding against smooth, hard surfaces, the surface structure of non-graphitic carbons can be transformed so that they can form a transferred layer which is graphitic in appearance.

Applications of graphite

It is a very widely used solid lubricant in countless applications at temperatures up to 500 deg C in air because of its relatively low cost and good performance. In metal working lubricant applications colloidal graphite dispersions are successfully used at much higher temperatures.

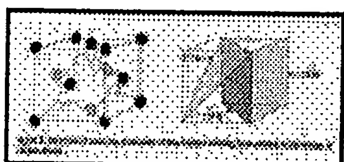

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Figure 2.

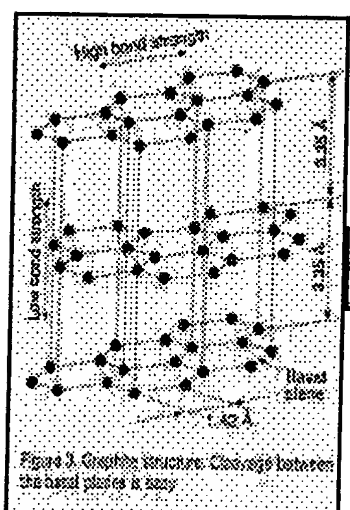

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Figure 3.

Other forms of carbon

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Recent developments have produced a further crystalline form of carbon. Carbon 60 is also known as Fullerene or less formal as buckyballs. Discovered ten years ago but not available in large quantities until recently, Fullerene, named after an American architect Buckminster Fuller because of the space-frame shape of the carbon 60 molecule, has molecules made up of 60 carbon atoms arranged in a regular pattern to form a cage shape resembling a football (Figure 5). There are already more than 100 Fullerene patents for mainly electrical, electronic and mechanical applications.

Tribological applications may be found for Fullerenes as sublimal films and oil additives.

Another relatively new form of carbon with proven good tribological properties is diamond-like amorphous carbon, referred to a DLC. In the form of thin coatings a few microns thick, applied at temperatures as low as 200 deg C, strongly bonded DLC is harder than tungsten carbide, yet has a very low coefficient of friction. Hardness values for DLC range from 5GPa to 130GPa (500 to 13,000HV) depending on the degree of hydrogenation from 50 per cent to zero, respectively. Hydrogenated DLC is shown as (a-C:H) and hydrogen-free DLC as (a-C). Little effect of hydrogen content on friction has been found but, unlike graphite, water vapour considerably increases the friction and wear of diamond-like films. DLC coatings are commercially available in the UK. In one, the good sliding behaviour of the coating is attributed to its structure of tungsten carbide-rich layers alternating with carbon-rich layers a few atomic layers apart.

Graphite fluoride, or poly(carbon monofluoride) (CF^sub x^), was discovered in 1934 when it was shown that graphite and fluorine would combine without combustion at temperatures between 420 and 550 deg C to form a light grey to white coloured solid. The approximate composition was CF^sub x^ where x was nearly equal to 1. The distance between the crystal planes of the graphite expanded from 3.35 to about 8 angstroms (0.8nm) in graphite fluoride (Figure 6) with a corresponding reduction in the cleavage strength. CF can be an attractive alternative to graphite because of its light colour, its lack of dependence on adsorbed layers from the atmosphere, and its poor electrical conductivity. Its performance as a solid lubricant is similar to that graphite and MoS^sub 2^ up to 420 deg C when it starts to decompose.

Mica is the name of a group of potassium aluminium silicates which have a well-defined lamellar structure and can be delaminated into thin, tough, transparent plates which have atomically smooth surfaces. Freshly cleaved faces of mica adhere very strongly. These strong forces, measured as about 20MPa, between the crystal faces give rise to high friction forces, demonstrating that lamellar structure alone is not sufficient for low friction. This force decreases with time as the cleaved surfaces are exposed to atmospheric contaminants.

The strong electrostatic (Coulombic) attraction between cleaved plates of mica arises because cleavage occurs across planes of potassium ions embedded in an alu mino-silicate matrix, with half the positively charged potassium ions in one surface leaving negatively charged sites in the other. The result is that the surface energy of mica is about 20 times greater than that calculated for graphite.

Applications: limited value as a solid lubricant up to 600 deg C but has excellent electrical resistance.

Molybdenum disulphide MoS^sub 2^ (Greek molybdos = lead) and graphite are so alike in appearance that they are often confused. They are both dark grey to black in colour, although graphite is more shiny. The crystal structure of MoS^sub 2^ is laminar, similar to that of graphite but, unlike graphite, MoS^sub 2^ is intrinsically a good solid lubricant with low friction maintained or reduced in a vacuum compared with the value in air. Its performance is adversely affected by an atmosphere of oxygen (possibly as a result of the formation of molybdenum dioxide) and is poor in wet air. There is evidence that finely divide MoS^sub 2^ slowly oxidizes at room temperature in moist air to produce the corrosive molybdic acid H^sub 2^MoO^sub 4^. Th reaction is commonly prevented by the incorporation in the powder of a fractional percentage of mineral oil.

The presence of gold in sputtered MoS^sub 2^ layers reduces the sensitivity of MoS^sub 2^ to its environment in ball bearing tests. The most common form of MoS^sub 2^ has a hexagonal crystal structure with planes of molybdenum atoms, sandwiche between layers of sulphur atoms with each atom of molybdenum equidistant from six atoms of sulphur placed at the corners of triangular prism 3.16 angstroms high (Figure 7). Strong covalent bonds hold the atoms of molybdenum and sulphur together. The spacing between adjacent layers of sulphur atoms is relatively large and the van der Waals type bonding between them is weak so that cleavage (separation of intercrystallite basal planes) easily occurs. MoS^sub 2^ belongs to the family of binary compounds known as dichalcogenides, mainly disulphides, diselenides and ditellurides of transition metals such as tungsten, tantalum, niobium and molybdenum, many of which have good solid lubricating properties and can withstand higher temperatures.

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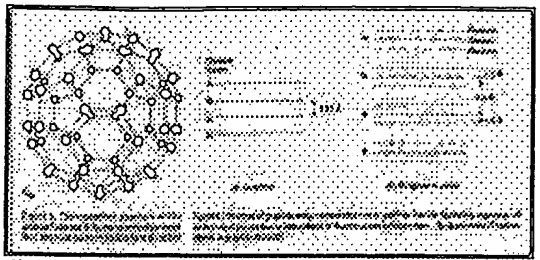

Figure 5.
Figure 6.

Natural MoS^sub 2^ occurs as large single crystals but the mineral molybdenite which is the main source of MoS^sub 2^ occu mainly in thin veins in rock. Extraction is by crushing the ore and liquid flotation. The amount present is only about one per cen with the remainder being silica and other abrasive impurities. For lubricating purposes, high purity (> 98 per cent MoS^sub 2^) powders are needed. The temperature limit in air above which there is increasingly rapid oxidation to molybdenum trioxide, a poor solid lubricant, is 370 deg C. Moist air lowers the onset of oxidation to 350 deg C. In the absence of air, MoS^sub 2^ is thermally stable to over 500 deg C and, under high vacuum, it dissociates above 1,000 deg C to molybdenum and sulphur.

Historical background

The use of MoS^sub 2^, then known as "water lead", dates back to the Middle Ages as a machinery lubricant in place of soap. was probably used as a wagon wheel lubricant in the USA during the great trek west in the 1880s. Its use in a mixture of sever other solid lubricants was first patented in 1927, but it was not widely available as a commercial solid lubricant until the early 1950s. After erratic friction in a fatigue testing machine was cured by the application of MoS^sub 2^ in 1935 the Sonntag Scientific Corporation was founded in the USA to carry out research into the lubricating properties of MoS^sub 2^ powder. Products containing MoS^sub 2^ have been developed and marketed under trade names such as Molykote, Molydag and Mol Paul.

Applications: MoS^sub 2^ adheres readily to most metal surfaces, except aluminium and titanium, and on burnishing forms a reasonably durable film. It is possibly the best all-round solid lubricant for temperatures up to 350 deg C where its higher cost than that of graphite is acceptable.

A 10:1 by volume mixture of MoS^sub 2^ and lead sulphide PbS has been found to perform well at temperatures above 500 de C and still be acceptable at room temperature, the inorganic sulphide having a synergistic effect on the load carrying capacity the MoS^sub 2^ buffed film (Table I).

Talc is the name given to a range of magnesium silicate powders obtained from naturally occurring steatite or soapstone. Although, as can be seen from the idealized formula Mg^sub 3^Si^sub 2^O^sub 10^(OH)^sub 2^, talc is similar in composition and structure to mica, it does not contain potassium and the cleavage plane is electrically neutral. This means that the forces binding the cleavage planes together are of a van der Waals type and very weak. This leads to the friction between flakes of ta being low. Laboratory tests have shown that talc is a poor solid lubricant for metals although in the past it was recommended, for example, for lubricating axles. The explanation may lie in its softness and poor affinity for metal surfaces, in contrast to graphite and molybdenum disulphide. When rubbed between finger and thumb talc feels very slippery.

Vermiculite is a lattice layer hydrated magnesium-aluminium-iron silicate mineral related to talc and mica and used like them a a parting agent in metal working. When heated to around 1,000 deg C it exfoliates and expands up to 20 times its original volume into long wormlike threads - hence its name.

Other inorganic materials

Soft metals

Soft metals like lead, indium, copper, gold and silver have the low shear strength needed for low friction. In most applications they need to be strongly adhering to the substrate and in the form of thin films. They are also used as lubricant additives in greases for screw threads. Thin coatings of soft metals are used to aid the bedding-in of bearings and gears. An important role of lead films is as a lubricant for rolling element bearings in space mechanisms. Lead is an exceptionally good lubricant in spac but relatively poor in air. Silver is used in NASA's PS200 composite (see later). Many proprietary products have been marketed based on soft metals. A typical example is one called Coleadium, its name suggesting that it contains copper, lead and aluminium. As a solid lubricant it was recommended for use on worn or corroded machine tool bearing surfaces, on hydraulic valves, in diesel engines and in electric motors. Coleadium was described as rebuilding bearing surfaces, preventing wear and "will reach a mirror finish, filling the troughs and valleys on the bearing surface and thoroughly plating the points of frictional contact". Coleadium powder was applied by "pressing the powder against the surface and burnishing the powder in

place by friction".

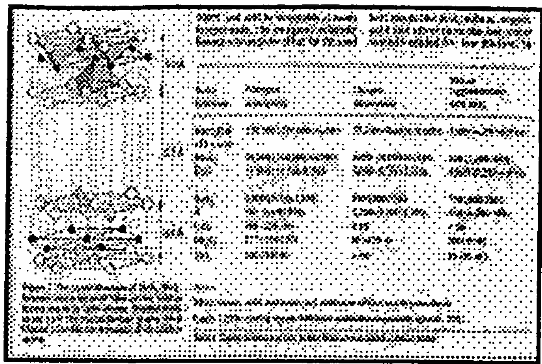

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Figure 7.
Table I.

Oxide films

The friction and wear reducing action of the oxide films which form rapidly on most clean metal surfaces is probably the most important and least acknowledged of all the solid lubricants. These oxide layers, as thin as 0.01 micrometres, can form within a few minutes and greatly reduce friction and local welding between sliding metal surfaces. The effectiveness of the oxide layer a solid lubricant is influenced by its hardness relative to that of its substrate. A soft oxide layer on a harder substrate gives low friction and is preferable to the ice-on-mud effect of a hard layer on a soft substrate such as is found with aluminium and magnesium.

Anodizing

Electrolytic processes such as anodizing, the main types being chromic, sulphuric or hard anodizing, produce a thicker, strong oxide layer on aluminium which gives greater protection. Being porous the anodized layer can be infiltrated with solid lubricant enhance its tribological properties. Ticote is an effective proprietary anodizing process for titanium.

Lead monoxide

Lead monoxide PbO has been found to be an effective solid lubricant at temperatures up to 550 deg C. Even at room temperature it gave respectable lives in wear tests (Table I). Between 400 and 500 deg C the conversion to the non-lubricant Pb_3O_4 occurs in an oxidizing atmosphere. Fusing PbO with a few per cent silica SiO_2 controls the oxidatio of PbO. PbO is also used with a waterglass (sodium silicate) binder as a high temperature lubricant. Mixtures of PbO and graphite perform well at temperatures up to 450 deg C.

Calcium hydroxide

Calcium hydroxide is claimed to act as a solid lubricant by the production of a layer of ferrosoferric Fe_3O_4 iron oxide on the rubbing surface of steel. This oxide has better tribological properties than the more common alpha-Fe_2O_3 ferric oxide. Benefits are attributed to its more favourable close-packed cubic lattice structure compared to the corundum-like lattice structure of ferric oxide, which oxide, in the form of rouge, is used as an abrasive for polishing metals.

The reaction between calcium hydroxide and hot iron, that is iron on the verge of scuffing, is given as:

$$3Fe + 4Ca(OH)_2 \leftrightarrow Fe_3O_4 + 4Ca + 4H_2$$

To be effective, the calcium hydroxide as an additive in oil has to be very finely divided with a specific surface area greater tha $20m^2/g$. Coarse particles may increase wear through abrasion.

Metal halides (fluorides, chlorides, bromides and iodides)

Many metal halides have been found to be effective as solid lubricants on their own or as additives to solid lubricants.

Calcium fluoride CaF_2, like some other metal fluorides, has proved an effective lubricant both for metals and ceramics a high temperatures up to 1,000 deg C. In a ceramic binder CaF_2 has been used as a lubricant for nickel alloys and in a sodium silicate binder it reduces the wear of ceramics at 500 deg C. Barium fluoride BaF_2 and cobalt chloride CoCl^sub

2^ gave low friction values in tests, as did cadmium iodide CdI^sub 2^ and copper bromide CuBr^sub 2^. Lead iodide PbI^sub 2^ and BaF^sub 2^ reduced the "dusting" wear of carbon brushes in electrical equipment used at altitude.

Metal sulphides

Molybdenum disulphide and many disulphides and diselenides of other high melting point metals such as tungsten, tantalum and niobium, known collectively as transition metal dichalcogenides, have crystal structures similar to that of MoS^sub 2^ and are good but expensive solid lubricants. Lead, zinc and cadmium sulphides have been used in applications at temperatures up to 500 deg C.

Lead sulphide PbS, bonded with boric oxide B^sub 2^O^sub 3^ in the ratio six to one by weight, was tested at two loads, two speeds and two temperatures. At the lower speed of 22m/s, the coating gave very promising results at 540 deg C but was poo at the lower temperature 371 deg C. When the speed was increased to 66m/s, wear was higher at the higher temperature than at the lower. The addition of PbS was effective in improving the performance of MoS^sub 2^ in humid and oxidizing environments.

Organic polymers

Polymers with smooth molecular profiles and without any side groups, such as polytetrafluoroethylene (Figure 5) and polyethylene, are low friction materials. This is because it is easy for the molecular chains to slide over each other. When in sliding contact, a very thin film of polymer is transferred to the counterface surface resulting in sliding of polymer over polymer and low friction. Many commercial forms of low density polyethylene have bulky molecules with straggly side groups which cause friction to be high and the transfer layer to be lumpy. To counteract this, a few hundred parts per million of a solid lubricant such as stearamide C^sub 17^H^sub 33^CONH^sub 2^, the amide of C^sub 18^ fatty acid, is incorporated in the polymer. This diffuses to the surface to form a low friction barrier layer.

Fluoropolymers

Solid fluoropolymers contain a wide range of compounds, of which the best known is the fluorocarbon polytetrafluoroethylene PTFE. Discovered by chance in 1938, it is a white, waxy solid with exceptional chemical resistance, thermal stability and anti-stick properties which has a low coefficient of friction over a temperature range from -200 to +270 deg C. There are several proprietary products based on the solid lubricating properties of PTFE. On its own, PTFE has a high wear rate and poor resistance to cold flow, but it responds well to fillers such as lead, glass, carbon, and bronze. It also acts as an effective impregnant in selflubricating bronze bearing materials. Because of its very high melt viscosity of over 10GP PTFE is difficult to process by the usual thermoplastic techniques. PTFE is available as a dispersion or in granular form. Production of solid parts by ram extrusion or by compression moulding and sintering. Processing difficulties have encouraged the search for other simil materials. The nearest in properties to PTFE have been fluorinated ethylene propylene FEP (also known as tetrafluoroethylene hexafluoropropylene copolymer) and perfluoroalkoxy resin PFA (also known as tetrafluoroethylene perfluoroalkylvinylether copolymer). FEP was first introduced in 1956. It has mechanical properties similar to those of PTFE and frictional properties almost as good. The maximum service temperature is 200 deg C and the polymer can be melt processed.

PFA was first marketed in 1973. It has better mechanical properties than PTFE and a similar maximum service temperature. It chemical resistance and frictional properties are excellent, although not as good as those of PTFE, and it can be injection moulded and extruded (see Table II).

In volume terms, the main applications of PTFE are in chemical processing equipment and plant, and for high temperature electrical components. As a solid lubricant, PTFE is used in dry powder form, with a binder in dry lubricant coatings, impregnated into the pores of bearing materials, as a lubricant additive and as a thickener in greases.

Soaps and waxes

Metal soaps and amides of long chain fatty acids such as calcium stearate and dimethyl stearamide, waxes, solid fatty acids such as stearic and palmitic acids, and esters such as lard and tallow are examples of organic solid lubricants. The most effective of these are polar compounds having active groups in a long chain molecule, presumably because the reactive group attaches itself to the surface being lubricated and resists removal. They often give the lowest friction obtainable with solid lubricants but in general cannot be used above their melting points or at very high loads. On melting, some continue to lubricat by forming compounds such as soaps having higher melting points.

Stearic acid C^sub 18^H^sub 36^O^sub 3^ with a melting point of 69 deg C proved effective as the lubricant for the stainless steel against copper alloy spindle screw threads of globe valves for use in controlling the flow of oxygen. Polar compounds as rubbed films have been used on the highly finished surfaces of air bearings to protect against damage on stopping, starting an overload. The use of stearamide to lubricate polyethylene sheet has already been mentioned.

Chemical conversion films

As well as the naturally occurring oxide films present on the surface of all base metals exposed to the air, other solid lubricant films can be formed by chemical or electrochemical action on the metal surface. A number of proprietary processes are available which convert metal surfaces and often increase their hardness, both of which improve the friction and wear characteristics.

Phosphate

Phosphating is a widely used chemical process for pretreating ferrous and zinc surfaces prior to coating. The manganese phosphate process, in particular, significantly improves the performance of solid lubricant coatings. Treatment with phosphoric acid, containing secondary and tertiary metal phosphates along with other anions which act as metal accelerators, chemically converts the metal surface. In the manganese phosphate process iron/ manganese crystals are formed which become an integral part of the surface. In the US military specification DOD-P1632, a coating weight of 2 to 3g/ft^sup 2^ (22 to 32g/m^sup 2^) is specified for good adhesive and wear properties. The vital importance of metal surface pretreatment is illustrated by the results of LFW-1 pad-on-ring wear tests (ASTM D-2714) on a phenolic bonded MoS^sub 2^/graphite coating run at 72rpm und 6301b (285.6kg) load (see Table III).

Phosphate treatments decompose when the temperature is raised, limiting their use to applications where the temperature is below 250 deg C.

Method of application of solid lubricants

The well-established methods of applying solid lubricants include:

Unbonded films:

Tumbling small parts in a container to which the lubricant powder has been added.

Dispersing solid lubricant powder in a gas stream directed at the surfaces to be lubricated.

Sacrificial transfer from a mating component such as a bearing cage, bushing, gear or from a block of lubricant such as in the case of rail wheel flange lubricators.

Applying as a suspension in a liquid which then drains or evaporates off to leave a dry film of solid lubricant.

Dispersing in a grease, paste or oil which also contributes to the lubrication, the solid lubricant acting as an additive.

Bonded films:

For thicker, more strongly bonded layers with better wear resistance some type of binder is used. The binder can be a lacquer an organic resin or an inorganic binder such as sodium silicate, phosphate, borate or ceramic. A low viscosity, volatile carrier is often added to facilitate application by brushing, dipping or spraying.

Incorporation in a porous matrix or porous surface layer (examples are the PTFE-containing products Armourcote and Glacier DU).

Chemical reaction of the bearing surface with a reagent to form a lubricating layer. Examples are the action of hydrogen sulphide on molybdenum and of halogen substituted hydrocarbon vapours on steel.

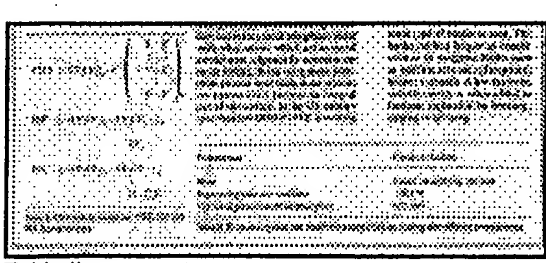

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Table II.
Table III.

Composite plated layers (electroless nickel and PTFE) or hard nonmetallic phases (Tribomet T 104C cobalt matrix with a chromium carbide dispersed phase).

Plasma spraying, where the solid lubricant can withstand high application temperatures.

More recently, physical vapour deposition (PVD) techniques carried out in a vacuum (typically 10^sup -2^ torn or 1.3Pa) developed for the micro-electronics industry have been adopted. Giving excellent adhesion and sub-micronthick films, these include:

Ion-plating, a plasma assisted PVD process in which the solid lubricant is evaporated, ionized in an argon ion plasma and drive by an electric field on to the bearing surface (Figure 8).

Sputter deposition, a cathodic spraying process in which the component to be coated is located opposite a target (the cathode made of the solid lubricant. Argon ions in a plasma are accelerated at the lubricant, causing atoms of the lubricant to be ejecte which then condense on the component. The applied power with a potential of 500 to 5,000V is generally DC (direct current) fo metal targets and RF (radio frequency of 13.56MHz) for non-conducting targets such as molybdenum disulphide. A magnetron source is often used to create a magnetic field which increases the plasma density and reduces component heating, allowing much greater sputtering rates.

The advantage of sputtering over. other coating techniques is shown in Figure 9.

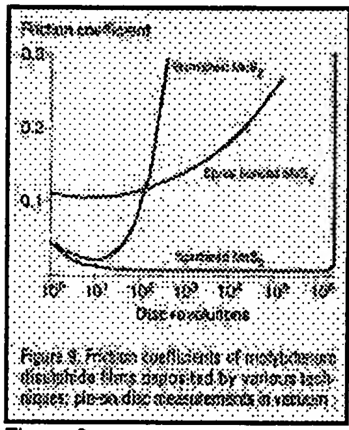

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Figure 9.

Mixtures of solid lubricants

Many solid lubricants have their performance improved when mixed with others having a different composition. This synergism applies in particular to MoS^sub 2^ where the presence of 10 per cent of inorganic sulphides has been shown greatly to increase the load capacity sliding against steel.

The benefit of adding graphite to MoS^sub 2^ has been explained by suggesting that the graphite acts as an anti-oxidant and moisture scavenger and facilitates the intercrystalline slip of MoS^sub 2^.

When solid lubrication over a range of temperatures is needed, a mixture may be chosen to include lubricants which include constituents which together cover the whole range. An example is the family of powder metallurgy (PM) and plasma sprayed (PS) composites PM/PS 200 developed by NASA (National Aeronautics and Space Administration) for temperatures up to 800 deg C. They comprise a wear resistant metal matrix of nickel and cobalt bonded chromium carbide containing the solid lubricants silver and barium/calcium fluoride eutectic. The widely used PS212 coating has, by weight, 70 per cent of the matrix 15 per cent silver (the low temperature lubricant) and 15 per cent barium fluoride/calcium fluoride eutectic (the high temperatur lubricants). Friction coefficients are typically within the range 0.25 and 0.4. Applications are in cryogenic process control valves variable temperature process control surface bearings, high temperature internal combustion engine (adiabatic engine) cylinde bore coatings and gas turbine seals and bearings.

Mixtures of graphite and sodium or cadmium sulphate are effective over a wide temperature range. The mechanism is thought to be one of graphite being bonded to the surface by an oxide layer.

A mixture of MoS^sub 2^, graphite, zinc sulphide and calcium fluoride gave good results in four-ball tests.

The wear resistance of PTFE in a bronze matrix is substantially improved by the inclusion of 20 per cent metallic lead, as is demonstrated by the success of Glacier DU, a proprietary dry bearing material with that type of surface. Tests of angular conta ball bearings under space conditions showed that PTFE retainers worked synergistically with MoS^sub 2^ coatings on the ball and races to give longer lives and lower torques in space satellite gimbal bearing tests.

Good performance at 500 deg C in vacuum was given by silicon nitride ball bearings with a hot pressed composite solid lubricant cage comprising 80 per cent molybdenum disulphide/10 per cent molybdenum dioxide/10 per cent niobium.

Case histories

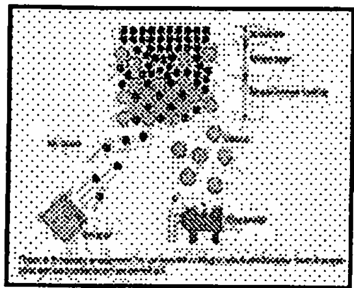

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Figure 8.

Wear increased by graphite in grease

From time to time there are reports of graphite as a lubricant additive increasing wear instead of having a beneficial effect on th lubricant. In one incident, several grease pumps were found to have suffered excessive wear after years of satisfactory operation. To explore the cause, long-term tests were carried out on an axial piston grease pump with 10, 11, 15 and 25 per cent by weight graphite in the grease. It was found that the pistons, swashplate and control valve had all worn, with wear increasing in proportion to the graphite content. It was suggested that the cause of the wear was chemical removal of the oxide film from the rubbing surfaces by reduction and then the graphite prevented the air from renewing the oxide layer. Abrasive we by impurities in the graphite was another possibility. A second series of tests was carried out in an FZG backto-back gear test machine. It was found that increasing the graphite content reduced the rating of the lubricant, as follows:

Graphite content (%w)	FZG scuffing load stage
10	10
11	9
15	8
25	6

Enlarge 200%
Enlarge 400%

The grease with 25 per cent graphite caused the greatest wear, while the grease with the lowest solid lubricant content caused the least. The opposite effect was found when oils with 5, 10, 15 and 25 per cent graphite were tested on a Reichert crossed axis machine with wear being greater the lower the graphite content.

MOS^sub 2^ as an assembly lubricant

When the change from brass to steel cages for ball bearings was made, problems were experienced in assembly with the rivet The 0.04mm oversize rivets used were found too tight a fit in the new cages. Rather than make expensive changes to the rivet the production tooling and the process, a tribological solution was sought. Preoiling messed up the assembly machines, jamme the rivets in the feed tube and failed in many cases to ease penetration. After months of trials, the solution found was to tumble the rivets in powdered molybdenum disulphide, making sure any excess powder was removed. This approach had originally been resisted because of bad experiences with MoS^sub 2^ suspensions in oil in the past caused by the tendency of the solid lubricant to build up and reduce clearances in the bearings.

Graphite for furnace trolley wheel bearings

The phosphor bronze half-bush bearings for the wheels of trolleys in a steel works tended to seize in service because the graphite inserts in the bushes became available for lubrication purposes only as the phosphor bronze wore. The trolleys carrie steel ingots very slowly through a preheating furnace where the temperature was 1,000 deg C. Extra lubrication using molybdenum disulphide-filled grease applied by hand was tried but was not effective and the grease tended to carbonize. The problem was solved with a cheap automatic spray of a colloidal suspension of graphite in water. This was applied on the return track while the axles of the trolleys were hot enough to evaporate the water immediately. There were no more stoppages through this cause.

Automotive vehicle component lubrication

The largest single user of lubricants is the automotive industry. Significant advantages in wear resistance and reduced friction from the presence of stable solid lubricant dispersions in engine oil have been demonstrated, but some less obvious disadvantages have prevented engine oil suppliers and engine manufacturers from recommending their use. Elsewhere, solid lubricants have played a vital role in improving the reliability and reducing the maintenance requirements of vehicles. The constant velocity joints (CVJ), which all front wheel drive cars must have, were originally oil lubricated. Very early on, the benefits of molybdenum disulphide were recognized in combating fretting wear and improving boundary lubrication. Graphite, zinc oxide, calcium carbonate and calcium phosphate were also tried. In the 1960s a typical CVJ grease would have contained at least 3 per cent MoS^sub 2^ and a lithium 12 hydroxystearate thickener. This is now being challenged by greases with part-synthetic fluids, different thickeners such as lithium complex or polyurea and greater attention to the particle size and structure of solid lubricants. Solid lubricants have caused problems with today's improved designs of CVJs and their closer clearances through noise and damage to the surfaces, a situation that can be improved by reduced particle size.

Needle roller universal joints and vehicle suspension and steering link ball and plastic lined socket joints are generally lubricate for life with greases containing solid lubricant, usually MoS^sub 2^.

Piston skirts and the surfaces of sliding or plunging joints in transmission drives can be coated with high temperature resin-bonded solid lubricant.

Grease recipe

The recipe for a lubricant suitable for a bearing subjected to vibrational movement was given in a French text 30 years ago. It was, in parts, by weight:

25 sulphur (to act as a mild abrasive to remove surface asperities).

25 graphite (to act as a solid lubricant and enhance surface adsorption).

10 fatty acid (to react with the oxide wear particles to form soaps).

40 lithium soap-based grease with good shear stability.

Leavers lace machines

Leavers machines for making dress lace have a lubrication problem where the oscillating steel carriage rubs against the brass circle strip (Figure 10).

Wear also occurs between the steel carriage and steel comb bars, and the carriage and bobbin. Traditionally lubrication was b fine flake graphite applied by shaking a woollen sock or perforated bag containing the graphite above the part to be lubricated. This was effective, but the black graphite could stain the mostly white lace and was difficult to remove during the scouring process.

Being white, PTFE seemed the answer but it was more difficult to apply, less adherent to the surfaces resulting in greater wea and did not prevent corrosion as well as graphite seemed to, When a mixture of graphite and PTFE was tried, it was found tha the graphite coated the PTFE making it black. Boron nitride mixed with PTFE was the right colour but proved ineffective as a lubricant. The shortterm solution was found by spraying daily with a fluorocarbon telomer, a dry film lubricant similar to PTFE. The product was called Rocol LF. Today's equivalent would be Rocol IFL, where IFL stands for invisible film lubricant.

Gas bearing solid lubricant

An effective solid lubricant for use over a wide range of tempertures is a sodium silicate-bonded mixture of cadmium oxide, silver and graphite with the composition, by weight:

15%	45%	10%	30%
CdO	graphite	silver	Na_2SiO_3

Enlarge 200%
Enlarge 400%

This solid lubricant was found effective on gears at 540 deg C and better than molybdenum disulphide at 290 deg C. When us to lubricate cobalt/chromium angular contact ball bearings running at 30,000rpm, lives of 70 hours at 540 deg C and 12 hours 650 deg C were achieved. Graphite with inorganic salts and oxides is thought to lubricate better because of interstitial or intercalation compounds with the graphite. A drawback of sodium silicate at room temperature is that it is hygroscopic.

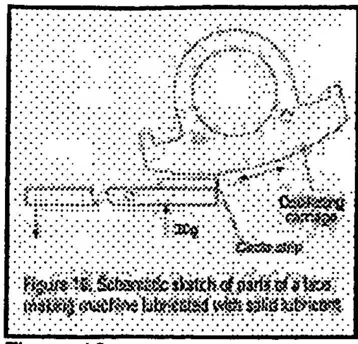

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Figure 10.

Solid rocket booster bearing lubrication

Solid lubricants have been used in aircraft since the 1950s. As speeds rose to Mach 2, and then to Mach 3, there was a need for a high temperature lubricant. The space shuttle solid rocket booster has its external tank attached by adjustable struts with ball joints to allow for relative motion between booster and tank. The solid lubricant system comprises a sprayed base coat of a ceramic frit, graphite and lead oxide mixture on an Inconel 718 nickel alloy ball. This is cured at 538 deg C and a top coat of resin bonded molybdenum disulphide and graphite is applied and cured at 260 deg C. The final operation is to burnish and produce a finish which is readily inspected.

Plastic moulding lubricants

Lubricants or parting agents for plastics processing include metal soaps, paraffin waxes, wax-like polymers (such as Carbowa and Oxidwachs polyethylene oxides), higher fatty alcohols, and fatty acid esters and silicones. They reduce the viscosity of moulding compounds by an internal lubricating action or are effective as external lubricants between the plastic and metal wall Finely ground calcium carbonate facilitates the extrusion of PVC (polyvinyl chloride) and enhances the polymer's impact strength by encouraging the sliding of the PVC molecules over the surface of the fillers present.

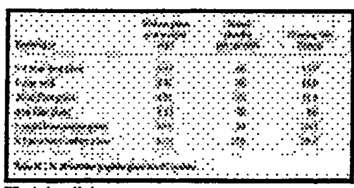

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Table IV.

Glass bottle mould lubricant

A dispersion of natural flake graphite in water with potassium silicate binding agent containing 35 per cent solids was used to coat blank moulds used for producing glass bottles. The aim was to reduce the need for regular swabbing with a solid lubrican dispersion. The bonded dry coating increased production efficiency by an average of 20 per cent compared with the swabbing treatment and gave lives of up to 25.5 hours (Table IV).

K.S. Paul Products

K.S. Paul was founded in 1955 in London to develop, make and market a range of lubricants incorporating molybdenum disulphide. The range of lubricating oil additives marketed under the trade name Moly-Paul now includes products such as ant seize compounds, dry film coatings, Easyrun assembly pastes with over 50 per cent MoS^sub 2^ content, bearing greases containing solid lubricants, transmission lubricants and solid lubricant dispersions.

In the 1960s subsidiary companies were set up in Germany and later in France and the group still exports the bulk of its production, After six years as a subsidiary of William Hudson Group, K.S. Paul became independent again in 1973 after a management buyout. Throughout its history, the group of companies has been led by the joint founder H. Peter Jost, now the president of the International Tribology Council and, although in his fourth quartile, still very active as group chairman and on th tribology scene both in the UK and internationally.

In 1989, K.S. Paul Products was forced to move a few hundred yards to the old Ever Ready battery site to make way for road developments connected with upgrading the North Circular Road. This severely disrupted production. Now at last the new, enlarged, computer controlled automatic production facility is fully commissioned and the company is looking to expand its markets.

K.S. Paul Products services niche markets with high quality lubricants, many sold as concentrates to the trade for resale under other brand names. Best-known products include an antiseize paste containing copper and lead powder known as Poly Butyl Cuprysil, or PBC for short, (also available without lead for environmentally sensitive locations) for applications such as screw threads, cement kiln rings and automotive disc brake systems. Colloidal graphite dispersions in mineral oil and semi-colloidal graphite dispersions in water for diecasting and hot forging applications are a speciality sold under the trade name Zonal.

The product range also includes high purity MoS^sub 2^ dry powder, resin-bonded solid lubricant coatings for pistons and cha lubricants for temperatures up to 400 deg C.

K.S. Paul is the agent for the Du Pont Vydax range of fluorotelomers of PTFE. These form white, waxy dry films with exception anti-stick and release properties which are used as coatings on razor blades, as solid lubricant films and as fluid lubricant thickeners. Vydax is available as a dispersion of 5-micron particles in isopropyl alcohol. It can be applied by dipping, brushing and spraying.

Vydax ARE/IPA formulations containing resin binders are available in aerosol form as mould release agents and dry film lubricants for metals and plastics and can stand temperatures up to 260 deg C. A typical product is Moly– Paul Aero 5.

More details from K.S. Paul Products Limited, Eley Estate, London N18 3DB. Tel: 0181 345 5566; Fax: 0181 884 3255.

Rocol solid lubricants

Rocol Limited, (the name is an acronym from Ragasine Oil Company Limited), has roots as far back as 1832 before the introduction of mineral oils as lubricants. Leeds based since the Second World War when it made lubricants for aircraft catapults, the name Rocol was adopted in 1951. Rocol became part of the speciality materials and technologies division of the Morgan Crucible Group in the late 1980s. It specializes in marketing its own range of high performance Sapphire bearing greases, Tufgear gear lubricants, Tufdraw metalworking products and maintenance aerosols. Rocol includes solid lubricants in many of its products such as the High Load grade of Sapphire grease and has developed a number of MoS^sub 2^ bonded dr film coatings including the AS anti-scuffing spray and oxygen compatible DFSM spray, both suitable for use at temperatures up to 450 deg C.

ASP, antiscuffing paste, leaves a dry film of MoS^sub 2^ on surfaces after the petroleum jelly carrier has evaporated, and MT-LM is an assembly paste for precision parts.

Manufacturer's typical technical data for Rocol ASP:

Appearances	soft blue-black paste
Carrier	petroleum jelly
Drop point	over 100°C
Solid lubricant	molybdenum disulphide
Four ball test results (IP 239)	
• Weld load	398kg
• Wear load index	85
Temperature range	as a dry film lubricant – up to 450°C

Enlarge 200%

Enlarge 400%

MV-3 lacquer-bonded dry lubricant produces a layer of MoS^sub 2^ by dipping or coating once the volatile carrier solvent has evaporated. Applications are to gears, slides and fastenings. The method of application recommended for MV-3 air-drying lacquer is as follows:

clean or degrease the surfaces;

dry at 80 to 100 deg C;

apply Rocol MV-3 to workpiece while still warm, taking care to keep the liquid agitated;

dry at 80 to 100 deg C in an oven for 30 minutes;

remove from the oven and cool;

burnish with a soft cloth or leather;

examine for holes or discontinuities and retreat if necessary.

Rocol has recently rationalized its product range, reformulated some lubricants and changed packaging sizes. It has strengthened its range of food lubricants with approved ingredients including a chain fluid which foams to penetrate links more easily. CL 280 M is a new high temperature chain and conveyor lubricant containing MoS^sub 2^.

Another new product is IPX1 Dry Film which offers resistance to seizure and to corrosion "superior to zinc plating and galvanizing in many applications without the risk of hydrogen embrittlement". The greyish black coating is around 20 microns thick and suitable for use at temperatures up to 150 deg C.

Products which contain fluorocarbon solid lubricants such as PTFE include IFL Spray and Ultralube Instant Spray grease (suitable for use at temperatures up to 250 deg C).

More details from: Rocol Limited, Rocol House, Swillington, Leeds LS26 8BS. Tel: 0113 (2) 866511; Fax: 0113 287 (2) 159.

Branwell Group AVARC graphite

AVARC is the long-established trade name for graphite flake, powder and granules marketed by companies in the Branwell Group. Production is at C.R. Averill Limited, Wrexham, and T.S. Wilson, Epping.

Hundreds of grades both of natural and synthetic graphite are produced and processed to specifications to suit the needs of each customer. Powder particle sizes range from 2 to 53 micrometres and there is a range of carbon contents. The graphite is used both as a dry lubricant and in colloidal mixes.

More details from: C.R. Averill Limited, P.D. Centre, Wrexham Road, Cefn-Y-Bedd, Wrexham LL12 9UL. Tel: 01978 760464; Fax: 01978 762496.

Molykote lubricants

In 1948 the Alpha-Molykote Corporation was founded by Alfred Sonntag in the USA to produce and market molybdenum disulphide in powder form. Molykote KG was founded in Munich six years later and introduced Molykote A, an engine oil additi to aid the running-in of engines. Dow Corning became involved in using MoS^sub 2^ as an additive in its silicone lubricants to compensate for the inherently poor boundary lubricating properties of many silicone fluids. As a division of the Dow Corning organization new technologies have been developed and today Molykote is a mark of quality for high performance speciality lubricants. From the earliest days, Molykote has had the backing of a technical service department staffed by experienced engineers whose sole task is to advise customers and solve their lubrication problems. In 1991 Molykote published an excellen 552page guide to the use of lubricants, treating the lubricant itself as a functional element of mechanical components. Althoug aimed specifically at Molykote products, the guidance given has wide general application as a lubrication handbook. The Molykote range of solid lubricants covers MoS^sub 2^, graphite and PTFE as powders, suspended in liquids or greases and in organic or inorganic binders.

Molykote recommends its AF solid lubricant coatings for:

dry permanent lubrication of bolts, lock parts and magnets, etc.;

as a running-in aid for engines and gear parts;

for giving emergency running properties in hydrodynamic lubrication;

for corrosion protection;

as a substitute for environmentally hazardous coatings.

Molykote developed P 37, a metal-, sulphur- and halogen-free high temperature thread paste containing solid lubricants stable up to 1,400 deg C. High alloy steels and nickel alloys can suffer grain boundary penetration by low melting point metals such a lead, tin or zinc leading to stress fractures. In the presence of water vapour, sulphur, chloride and fluoride can cause corrosion of bolts made from these alloys. Nickel based pastes were not acceptable because of the carcinogenic effects of nickel powde

More details from: Dow Corning Ltd, Kings Court, 185 Kings Road, Reading RGI 4EX. Tel: 01734 507251; Fax: 01734 575051

Kluber solid lubricants

Munich-based KlUber Lubrication, a member of the Freudenberg Group of companies, is a major European supplier of high performance lubricants, many of which contain solid lubricants or are solid lubricant based. The Klubertop and Fluoropan rang of bonded dry coatings contain PTFE, the latter being suitable for use at higher temperatures up to 230 deg C. Applications are as assembly aids, for coating plastics and elastomers and to reduce friction and wear in dry contacts.

Molybdenum disulphide-based dry lubricants are Unimoly CP thermosetting coating for temperatures up to 220 deg C and Unimoly C 220 coating with a hygroscopic binder suitable for the temperature range -180 to 450 deg C. There are also Unimol greases containing MoS^sub 2^ to give emergency lubricating properties and Unimoly RAP paste with a high content of MoS^sub 2^, graphite and inorganic solid lubricant for extreme conditions to prevent fretting, wear and seizure.

Kluberdur KM 01-854 is a twocomponent solid lubricant for filling the pockets and holes in plain bearings.

Kluberplast is a range of moulded dry bearing materials based on PTFE from which bearing components can be machined. Kluberplast W2 is graphite filled.

Kluberbond is the name applied to a number of coating processes for metallic materials applied to reduce friction and wear and in some cases, prevent corrosion.

Kluber has always responded to demands for specialist lubricants ever since Theodor Kluiber developed bentone montmorillonite clay thickened high temperature greases before the war. The company has a comprehensive range of product backed up by many excellent guides to the lubrication of particular components, mechanisms and industries.

More details from: Kluber Lubrication Great Britain Limited, Hough Mills, Halifax, West Yorkshire HX3 7BN. Tel: 01422 205115 Fax: 01422 206073.

Lonza becomes Timcal

Lonza products are now distributed worldwide under the trade names Timrex (graphites and cokes), Rollit (lubricants and lubrication tech-nologies) and Timroc (silicon carbides), replacing the former Lonza product names.

The Timrex carbons are especially used for batteries, friction materials, carbon brushes and in powder metallurgy. Rollit Technology is sold as a lubricant additive package to the steel industry, and Timroc silicon carbides to the abrasive and firepro industries.

Lonza G&T Switzerland was sold to the French Imetal Group by Alusuisse-Lonza Holdings in 1994, and since 1 September 1995 it has been officially working under its new name Timcal Ltd.

The carbons produced by Timcal Ltd are outstanding for their good quality, their high purity with less than 0.1 per cent ash and their optimal properties which give the company a leading position in niche markets.

For further information please contact: Timcal Ltd, CH-5643 Sins, Switzerland. Tel: +41 42 66 0111; Fax: +41 42 66 2316.

Stuart Oil forging lubricants

Stuart Oil produces its Thermex range of forging and die casting lubricants, both water and oil based dispersions, containing 1 45 per cent graphite.

After extensive research and development the company has commissioned a new micronizing plant which mills, grinds and polishes the graphite for these lubricants to whatever particle size is required, more economically than the traditional method and with enhanced quality.

Field results confirm better than average die life and longer shelf life for the lubricants containing the graphite from the micronizing plant.

More details from: D.A. Stuart Oil Co. Ltd, Lincoln Street, Wolverhampton WV 10 0DZ. Tel: 01902 456111; Fax: 01902 453764

Achesons Colloids Company

Achesons set up business in Plymouth, attracted by the purity of the local water which it needed for its dispersions of solid lubricants. A subsidiary of Achesons Industries in the USA, the first British plant was established in 1910.

The product range covers Dry Assembly lubricants, Molydag dry film lubricants containing MoS^sub 2^, Emralon PTFE coatings, and DAG graphite-based dry film lubricants.

Achesons also offers solid lubricant additives to increase the load carrying capacity of oils and a wide range of solid lubricant dispersions in water, oil, synthetic fluid or volatile carriers for use as forging die lubricants, on hot conveyor chains and in other similar applications.

More details from: Achesons Colloids Company, Cattewater Road, Prince Rock, Plymouth PL4 OSP. Tel: 01752 266351; Fax: 01752 222343.

David Hart graphite powders

A major UK supplier of graphite powders is David Hart (Feckenham) Limited in Alchester. Its high purity Hart grades of graphit are milled to four standard mesh sizes. These are from 96 per cent passing 150 to 96 per cent passing 400, with in addition an extra fine Hart M grade. The two standard qualities are grade A and B comprising 99 and 98 per cent carbon, respectively. Controlled impurities are sulphur (< 0.06 per cent), nitrogen, volatiles (0.3 per cent) and ferric oxide (< 0.3 per cent in grade A) Ash contents are 0.06 per cent maximum in grade A and 1.0 to 1.5 per cent in grade B.

Solid lubricant dispersions in liquids such as water, mineral oils and alcohol are sold as lubricants for applications such as wire drawing, drop forging and stamping, die casting, metal forming and as conveyor lubricants.

Hydrol-lart H403 is a 20 per cent dispersion of graphite in water.

HartOil H401 is 10 per cent colloidal graphite in mineral oil.

HartOil H412 is a paste of 45 per cent graphite in oil sold as a grease additive.

HartCol H415 is 20 per cent graphite in a volatile carrier, alcohol.

MolyHart HMS10 is 10 per cent molybdenum disulphide in mineral oil.

The company also produces a range of pastes, greases and aerosols containing graphite.

More details from: David Hart (Feckenham) Limited, Bleachfield Street, Alchester B49 SBD. Tel: 01789 400221; Fax: 01789 400822.

Graphoidal Developments

Situated near the "Steel City" of Sheffield, Graphoidal Developments blends graphite dispersions under the Grad trade name f customers mainly in the steel hot forming and diecasting industries. Both flake and synthetic powders are used, with water-based products being the most requested. Another market is lubricants for glass dies.

More details from: Graphoidal Developments Limited, Wreakes Lane, Dronfield, Sheffield S18 6PN. Tel: 01246 419171; Fax: 01246 419172.

Du Pont expansion

Du Pont is expanding its worldwide granular, fine powder and dispersion capacity for its Teflon fluoropolymer resins by about 2 per cent to meet continued market demand and new growth opportunities through the year 2000 in the automotive, textile, met coatings, electrical and electronics markets.

The expansion for granular, fine powder and dispersion resins will be realized through more effective use of existing global facilities and processes for fluoropolymers, including manufacturing, technology and quality improvements. It is being phased i through 1997 at the company's Dordrecht Works plant in The Netherlands, Washington Works plant in the USA and Shimuzu Works plant in Japan.

The expansion programme for these homopolymers is part of a total Du Pont commitment to its fluoropolymer product line. It complements a capital investment programme Du Pont announced last September for copolymer resins involving significant installation of new equipment to achieve needed capacity for products such as Teflon FEP and PFA fluoropolymer resin used i electrical and electronics applications.

Bruno Daengeli, global business director, Du Pont Fluoropolymers, said that the homopolymer expansion will provide significa new capacity and give the company the flexibility to bring out new products in granular, fine powder and dispersion businesses at a time when its customers most need them for their growth and renewal efforts.

Du Pont's commitment to its fluoropolymers business and intent to strengthen continuously the position of Du Pont fluoropolymers and flagship brands such as Teflon in the marketplace with customers are evidenced by the homopolymer and copolymer expansions the company has undertaken.

Total world capacity of homopolymer resins from all fluoropolymer producers was about 50 to 60,000 metric tonnes in 1994. Capacity is divided equally among the USA, Europe and Asia Pacific.

Du Pont is a research and technology-based global chemical and energy company offering highperformance products based o chemicals, polymers, fibres and petroleum and serves worldwide markets in the aerospace, apparel, automotive, agriculture, construction, packaging, refining and transportation industries. Among Du Pont's best-known brands are: Teflon flouropolymer resins; Suva refrigerants; Silvertone non-stick finishes; Lycra spandex fibre; Stainmaster flooring system; Devlar aramid fibre; Tyvek spunbonded olefin; and Corian solid surface material.

More detail from: Du Pont (UK) Ltd, Wedgewood Way, Stevenage SGI 4QN. Tel: 01438 734835; Fax: 01438 734550.

Superior Graphite UK

Slip-plate is the trade name of a range of graphite-based products from the USA. They offer a means of lubrication in contaminated and unfriendly environments where conventional greases and liquid lubricants are unsuitable. Applied by brush o aerosol, they form a durable, dry, long-lasting lubricating and protective coating. The range includes heavy duty, general purpose and penetrating grades. The specially formulated chain and cable lubricants do not drip from chains in motion while extending the life of wire ropes and cables. A major success for Slipplate has been in lubricating the hydraulically operated slides acting as lifts on car transporters. Lubricating grease attracts dust and road grit causing them to wear and jam. Slipplate lubricates effectively and keeps the surfaces dust-free.

Aerosol containers (200 and 400m1) are available from: Superior Graphite UK, PO Box 600, Longridge, Preston PR3 3RW. Te 01772 786737; Fax: 01772 782737.

Easyslide

As a fine white powder containing PTFE, Easyslide is a low technology solution to lubrication problems with simple mechanism such as zips, locks and drawer slides. It is supplied in plastic "puffer" bottles by: Pegasus Products (Leeds) Limited, 17 Holt Park Grange, Leeds LS 16. Tel/Fax: 0113 261 1586.
